Implantation of a Novel Telemetric Intraocular Pressure Sensor in Patients With Glaucoma (ARGOS Study): 1-Year Results

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PURPOSE. We investigated the safety of a telemetric IOP sensor and the accuracy of its IOP measurements in six patients with open-angle glaucoma and cataract.

METHODS. The study design was a prospective, single-center clinical trial. Here we present 1-year follow-up data. A ring-shaped telemetric IOP sensor was implanted in the ciliary sulcus after implantation of the intracapsular lens, during planned cataract surgery. The sensor is encapsulated in silicone rubber and consists of a miniature device with eight pressure-sensitive capacitors and a circular microcoil antenna. IOP measurements are performed with a reader unit held in front of the eye. IOP is calculated as the differences between the absolute pressure inside the eye (pressure sensor) and that outside the eye (reader unit).

RESULTS. The sensor was successfully implanted in all patients. Four patients developed sterile anterior chamber inflammation that resolved completely within 9 days after surgery with anti-inflammatory treatment. All patients showed mild to moderate pupillary distortion and pigment dispersion after surgery. Telemetric IOP measurement was performed in all patients at all visits, and the patients successfully performed self-tonometry at home after receiving instructions. Telemetric IOP values showed similar profiles compared to those of Goldmann applanation tonometry (GAT). Three patients showed a relevant IOP step during follow-up, and in one patient, negative values were obtained throughout the study.

CONCLUSIONS. Despite early postoperative anterior chamber inflammation, the IOP sensor was well tolerated by all patients. We describe the first prospective clinical study of a noncontact IOP sensor that potentially enables continuous IOP monitoring in patients with glaucoma. The sensor shape and size needs to be adapted to avoid pupillary distortion and to confirm that IOP measurements are accurately recorded in comparison to those of GAT. (www.germanctr.de; number DRKS00003335.)

Keywords: glaucoma, intraocular pressure sensor, self tonometry

Glaucoma remains one of the major causes of blindness and visual impairment worldwide.[1] Apart from early detection and diagnosis of the disease, sufficient monitoring and treatment are essential for preventing vision impairment. Glaucoma can be a lifelong disorder, and patient compliance varies.[2] Therefore, clinicians must find ways to improve the patient's involvement in the disease course over the years.

Intraocular pressure (IOP) is a clinical measurement that specifically concerns patients with glaucoma. An increased IOP is the greatest risk factor for glaucomatous optic neuropathy.[3] However, glaucoma is a complex disease with several pathophysiological factors that the treating physician must take into account. The exact role of IOP in the disease course and its impact on the individual are not completely understood. Recent studies have suggested that short- and long-term IOP fluctuations may be an independent risk factor for the progression of glaucoma[4,5]; however, this finding remains controversial.[6] Standard tonometry techniques used in clinical settings at present typically allow only single IOP measurements that may not reflect the IOP fluctuations that occur over a 24-hour period; even less is known about nighttime IOP fluctuations. Additional data are particularly important for patients with unclear progressive glaucoma. Therefore, self-tonometry that provides reliable and repeatable IOP measurements may help us better understand the role of IOP fluctuations in the progression of glaucoma. In addition, self-tonometry would likely have a positive effect on a patient's compliance with daily treatments, using antiglaucomatous eye drops.

Here we describe the first successful implantation of a telemetric IOP sensor in patients with glaucoma in a prospective, single-center clinical trial (ARGOS study; Deutsches Register Klinischer Studien [German Clinical Trials Register] DRKS00003335; www.germanctr.de). Results from a previous animal study using a wireless IOP transducer indicated the device had good tolerability and provided measurements that closely agreed with manometric pressure measurements.[7] Melki et al.[8] recently first described a WIT implantation in a human eye with positive safety outcomes. The aim of the present study was to investigate the safety and feasibility of this novel telemetric IOP sensor and the accuracy of its IOP measurements in patients with glaucoma.

METHODS

Study Design

This was a one-arm, open-label, prospective single-center clinical trial. The study protocol was reviewed and approved

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TABLE. Patient Data at Baseline and at 1 Year After Implantation

Patient/Sex/Age, y	Study Eye	Diagnosis	Baseline IOP GAT, mm Hg	IOP GAT at 1 Year, mm Hg	Baseline Visual Field MD, dB	Visual Field MD at 1 Year, dB	Baseline Gonioscopy Findings	Gonioscopy Findings at 1 Year	Baseline Visual Acuity†	Visual Acuity at 1 Year*†
1/F/75	OD	POAG	13	18	−3.34	−6.07	Wide open angle; all structures visible	Narrow angle at 8 o'clock; no angle closure	20/63	20/25
2/F/76	OS	POAG	13	12	−4.94	−5.95	Wide open angle; all structures visible	Increased angle pigmentation; mild narrowing of the angle at 4 o'clock; no synechiae, no angle closure	20/25	20/25
3/F/71	OD	NTG	9	10	−28.08	−29.34	Wide open angle; all structures visible	At 8-10 o'clock, very narrow angle; no closure, no synechiae	20/63	20/32
4/M/72	OD	NTG	13	11	−22.59	−23.60	Wide open angle; all structures visible	At 6 o'clock, increased pigmentation; at 8-10 o'clock, very narrow angle	20/25	20/63
5/M/70	OS	NTG	15	8	−2.17	−2.19	Wide open angle; all structures visible	Increased pigmentation; no synechiae; at 1-2 o'clock, very narrow angle	20/20	20/16
6/F/73	OS	POAG	19	18	−25.05	−27.34	Wide open angle; all structures visible	increased angle pigmentation; angle narrowing at 5-8 o'clock; discrete anterior synechiae	20/32	20/63

MD, mean deviation; NTG, normal tension glaucoma; POAG, primary open-angle glaucoma.
* All patients showed advanced glaucomatous visual field defects that partially affected center visual acuity.
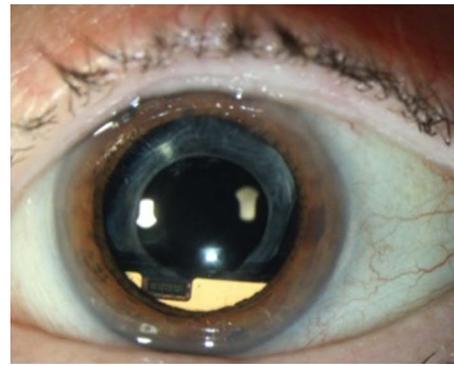† Using Early Treatment of Diabetic Retinopathy Study charts.

FIGURE 1. Documentation of ARGOS sensor and IOL position in mydriasis in patient 2. The iris covers the coil antenna. At the 6 o'clock position, the miniature device with eight pressure sensitive capacitors included in the single application-specific integrated circuit is visible.

by the institutional ethics committee and was conducted in accordance with the Declaration of Helsinki. All patients provided written informed consent before enrollment and were between 18 and 80 years of age.

Patients and Enrollment Procedure

All study participants were patients with cataract and existing open-angle glaucoma (primary open-angle glaucoma, normal tension glaucoma) that required cataract surgery. The individual target IOP in each patient with topical antiglaucomatous treatment had to be under control, avoiding the need for IOP-lowering procedures during follow-up examinations.

The study coordinator conducted a prescreening at our inpatient and outpatient clinics. Patients eligible to participate were informed of the study, and those willing to participate were invited to our clinic for screening or baseline assessments (screening visit V0). After the patients provided signed informed consent, their compliance with the inclusion and exclusion criteria was confirmed. The exclusion criteria included pregnancy, existing secondary glaucoma, an uncontrolled IOP condition, inner eye surgery performed in the 6 months prior to the screening, and an axial length of <22 mm. An inpatient surgery appointment was arranged for the 6 patients selected for the study, which included 2 men and 4 women (mean age: 72.8 ± 2.3 years old). The mean axial length was 23.71 ± 1.03 mm (range, 22.77–25.30 mm). Relevant clinical data for all patients are summarized in the Table.

Treatment

Surgery was performed with patients under topical eye-drop anesthesia in combination with peribulbar upper fornix anesthesia. The telemetric IOP sensor was implanted at the end of the cataract surgery, after intracapsular lens implantation, and it was implanted through a 5.5-mm corneal incision in the ciliary sulcus (Fig. 1). Healon injection (Abbott Medical Optics, Santa Ana, CA, USA) was used to widen the sulcal space. The sensor was then folded with forceps and implanted in maximal mydriasis. In accordance with the surgeon's decision, basal iridectomy was performed in the first three patients. Due to the necessity of a larger corneal incision, a nylon 10-0 corneal tunnel suture was used in these patients.

Safety Assessment

The sensor safety endpoints were regularly assessed throughout the study; these included medical history, best-corrected

visual acuity (using Early Treatment of Diabetic Retinopathy Study charts), visual field (static perimetry; protocol 24-2 SITA [Swedish Interactive Threshold Algorithm] Humphrey Field Analyzer [HFA; Carl Zeiss Meditec, Oberkochen, Germany]), IOP measurement (using Goldmann applanation tonometry [GAT], dynamic contour tonometry), slit-lamp examination, gonioscopy, ophthalmoscopy (retina, macula, and optic nerve with cup-to-disc ratio), Heidelberg retina tomography (Heidelberg Engineering, Heidelberg, Germany), endothelium evaluation (Confoscan; Nidek Technologies Srl, Padova, Italy), central corneal thickness (Pentacam; Oculus, Wetzlar, Germany), optical coherence tomography (OCT), ultrasound biomicroscopy (UBM), and assessment of adverse events. The following parameters were relevant for the primary endpoints: visual acuity; IOP; slit-lamp, fundus, and visual field examinations; gonioscopy; endothelium cell count; central corneal thickness; UBM; macular OCT scan; and adverse events.

Outcome Measures

The primary endpoints were the safety and tolerability of the intraocular sensor following implantation and long-term IOP measurements performed using the sensor. The secondary endpoint was the feasibility of patient self-tonometry using the IOP sensor and a reading unit.

Specifications of the Telemetric IOP Sensor

Todani et al.[7] previously detailed the technical specifications of the intraocular sensor. We have briefly reported some key technical points of the apparatus and data from previous animal experiments. The ring-shaped telemetric IOP sensor (ARGOS; Implandata Ophthalmic Products GmbH, Hannover, Germany) is a miniature device with eight pressure-sensitive capacitors included in a single application-specific integrated circuit (ASIC) combined with a circular microcoil antenna. The device is completely encapsulated in silicone, with an outside diameter of 11.2 mm and a thickness of 0.9 mm. The device is not battery powered but is powered by a high-frequency field emitted from the same reader unit that transmits the sensor data. During IOP measurements (duration: <2 seconds), the reader unit is held at a short distance in front of the eye.

The wireless IOP transducer has shown biocompatibility in rabbit eyes for up to 25 months with no signs of toxicity. Concordance with manometry data demonstrated transducer drift over time, thereby necessitating recalibration. Once recalibrated, the device showed a strong concordance with intraocular manometry over a wide range of pressures.

RESULTS

Safety and Tolerability

The IOP sensor was successfully implanted in each patient ($N = 6$), in the ciliary sulcus (Fig. 1). During implantation, we observed no dislocation of the intracapsular lens or visible changes in the iridocorneal angle. However, a significant pigment dispersion occurred during the implantation in patients 1, 4, and 6 (Fig. 1).

In the initial postoperative days, 4 of 6 patients developed significant sterile anterior chamber inflammation, and 2 of these 4 patients showed a hypopyon of 1.5 mm. In detail, patient 1 presented to the clinic on the third postoperative day with blurry vision. The examination revealed a significant fibrin reaction of the anterior chamber with a hypopyon of 1.5 mm. Patient 4 developed a hypopyon of 1.5 mm accompanied by pain on the second postoperative day. In both of the patients there was no posterior segment involvement, and anterior chamber probes revealed no bacteriological findings.

Nevertheless, as a precaution and due to the lack of experience, the authors started systemic antibiotic treatment (cefuroxime) as well as intensive anti-inflammatory treatment (prednisolone eye drops, 1%, and oral prednisolone). The inflammation resolved completely within 9 days after surgery in all 4 patients with serious anterior chamber reaction.

All patients showed a mild to moderate pupillary distortion after surgery (Figs. 2a–2f). Patients 1 and 4 showed transillumination of the peripheral iris owing to intraoperative pigment dispersion (Fig. 3).

In 5 of 6 patients GAT measurements revealed higher IOP values 6 months postoperatively than at baseline, which contradicted the expected IOP lowering effect after cataract surgery. Mean ± standard deviation (SD) IOP values were 13.7 (±3.3) mm Hg, ranging from 9 to 19 mm Hg at baseline; and 15.8 (±5.5) mm Hg, ranging from 8 to 25 mm Hg at the ninth follow-up visit (6 months postoperatively). However, 1 year postoperatively, GAT values (mean IOP: 12.8 ± 4.2 mm Hg; range, 8–18 mm Hg) normalized and reached baseline levels (Table). Nevertheless, pronounced fluctuations were observed in patients 2 and 6 during the 1-year follow-up (see Fig. 5).

There were, however, no incidents of severe IOP decompensation, pupillary blockage, angle closure, corneal edema, retinal detachment, endophthalmitis, bleeding, macular edema, or visual deterioration.

As expected, best-corrected visual acuity showed a letter gain after cataract surgery (Table). Confoscan measurements revealed no significant endothelial cell loss: the mean ± SD endothelial cell density was 2276.83 cells/mm² (±173.40; range, 2130–2599 cells/mm²) at baseline; 2281.25 cells/mm² (±312.52; range, 1935–2657 cells/mm²) at the ninth follow-up visit (6 months postoperatively); and 2243.25 cells/mm² (±302.17; range, 1944–2561 cells/mm²) at the 15th follow-up visit (1 year postoperatively). Similarly, mean central corneal thickness was 540.67 μm (±15.50; range, 522–569 μm) at baseline; 541.83 μm (±12.50; range, 524–558 μm) at the ninth follow-up visit; and 538.50 μm (±11.84; range, 525–553 μm) at the 15th follow-up visit. No significant progression in mean visual field deviation was observed 1 year after surgery (Table).

Anatomy and Refraction

UBM was performed to evaluate anatomical interactions and the effect of sensor implantation on iris configuration. In all patients, there was a symmetrical space of approximately 2 mm between the iris and intraocular sensor, with no sign of anterior or posterior synechiae (Fig. 4). However, the sensor appeared to contact the peripheral iris with some anterior distortion of the iridocorneal angle without angle closure. Because of visual artifacts, it was difficult to determine whether the sensor contacted the intraocular lens (IOL; IOL Master; Carl Zeiss Meditec AG, Oberkochen, Germany). In all patients, gonioscopy revealed a narrowing sectoral angle in the inferior circumference after 6 months and 1 year, respectively. One patient showed discrete anterior synechiae (at less than the 1-o'clock position).

No significant refractive errors occurred with the implanted intraocular sensor. After the corneal suture was removed, the largest astigmatism observed was −3.0 diopters (D). Postoperatively, the mean ± SD absolute error (Haigis algorithm) was 0.6 ± 0.4 D (range, 0.25–1 D). All patients showed a mean absolute error of ≤1 D; 3 of the 6 patients showed a mean absolute error of ≤0.5 D.

Sensor Functionality and IOP Measurement

Control checks performed immediately before and after the implantation showed no damages or impact of the implanta-
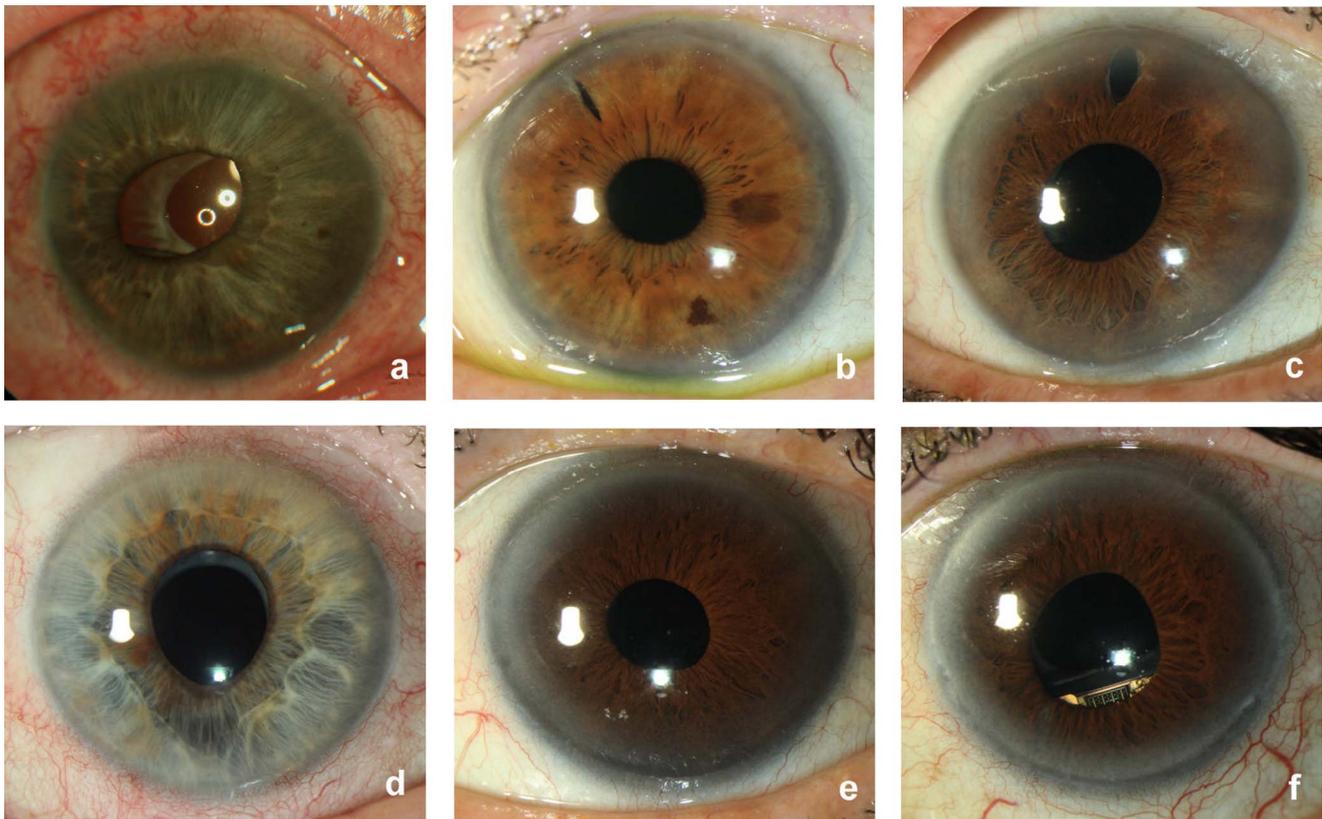
FIGURE 2. (a–f) Pupillary distortion of each patient at the 1-year follow-up visit (1 year after implantation of the IOP sensor [ARGOS] in the ciliary sulcus during cataract surgery).

tion procedure and folding on sensor functionality. Telemetric IOP measurements were successfully performed in all patients at all postoperative evaluations. The sensor measurements for each patient are presented with their corresponding GAT values in Figures 5a to 5f. These values were obtained during each follow-up visit and represent the mean value of three repeated measurements. All follow-up visits and, therefore, all

FIGURE 3. Transillumination of the peripheral iris in patient 1 resulting from intraoperative pigment dispersion caused by the sulcus implantation of the ARGOS sensor. The transillumination remained unchanged postoperatively over the 1-year follow-up period.
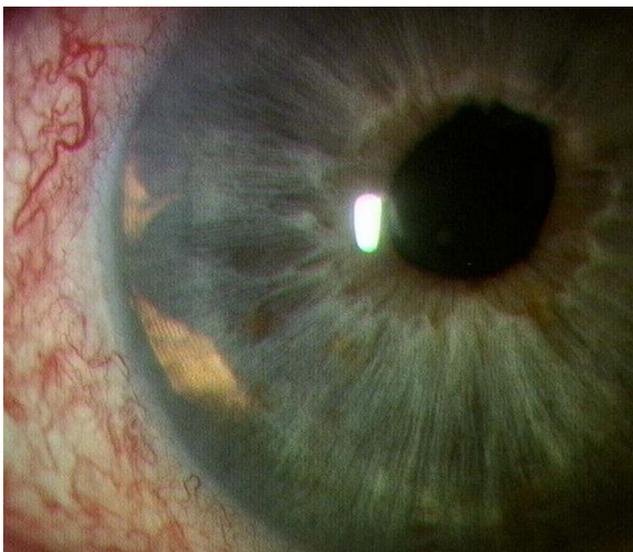
sensor measurements were performed at similar time points (approximately 8–11 o'clock in the morning). Patients 3 and 6 showed similar IOP profiles using the telemetric sensor compared to those with GAT (Fig. 5). Patient 2 also showed similar profiles, but a positive IOP step of approximately 10 mm Hg was observed after 5 months. Patient 4 presented negative telemetric IOP values throughout the study, with a positive IOP step after 6 months. For patient 5, a positive IOP step of approximately 15 mm Hg could be observed after 6 months.

Self-Tonometry

All patients successfully performed self-tonometry at their homes with the reader unit. They reported no pain or discomfort during the measurements. One patient initially experienced some difficulties with the measurements owing to orbital morphology consisting of a prominent frontal bone and deep-set eyes. After further instruction and adjustment of the holding angle of the reader unit, the patient could perform the subsequent measurements without difficulty.

DISCUSSION

The idea of continuous IOP monitoring is not new. In 1967, Collins[9] proposed an implantable device for measuring IOP. Technological advances in recent years have provided realistic approaches for IOP assessment. Two primary methods are described in publications: a noninvasive procedure that uses a contact lens sensor and an invasive design that uses implantable pressure sensors.[10–12] The advantage of a contact lens sensor is its noninvasiveness and tolerability.[13,14] However, the contact lens sensors were designed for 24-hour
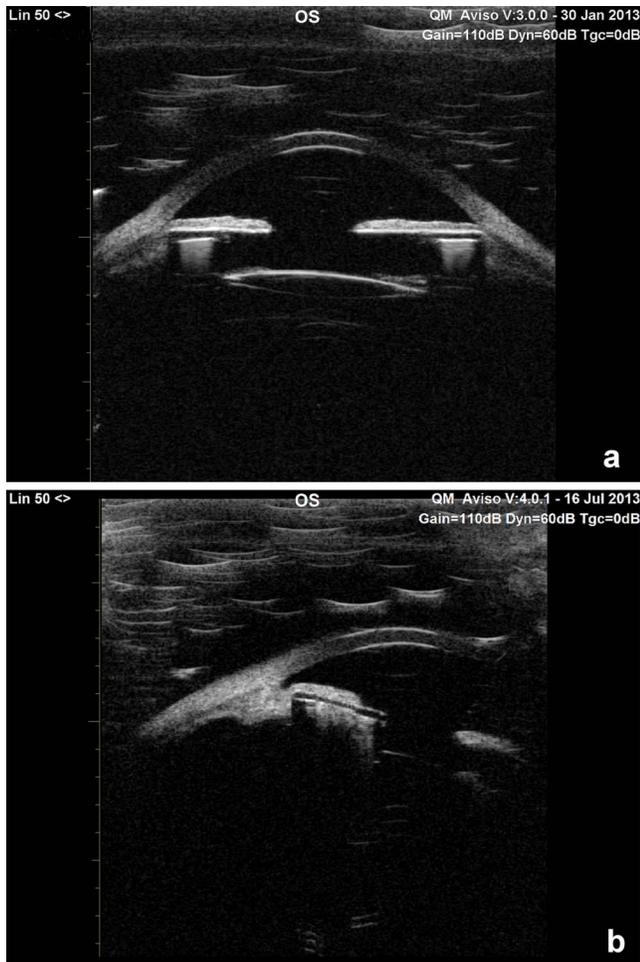
FIGURE 4. (a) Ultrasound biomicroscopy in patient 6 at the ninth follow-up visit (6 months postoperatively). Notice the space between the sensor and iris, which was 0.2 mm in all six patients. There seems to be contact between sensor outer diameter and ciliary body that is not clearly visible due to visual artifacts. (b) Inferior angle segment of the same patient at 1-year follow-up. Notice the sensor contact with the peripheral iris with a degree of anterior distortion of the iridocorneal angle without angle closure.

intraocular pressure monitoring, and they cannot perform long-term IOP assessment. Furthermore, there are concerns regarding how the corneal properties may affect IOP measurements.[15,16] The concept and design of implantable devices have been modified over the last few decades. Earlier models showed difficulties with signal strength,[17] whereas Schnell et al.[18] and McLaren et al.[19] presented models in 1996 that obtained accurate telemetric data in rabbit eyes in vivo. Their devices, however, were not fully implantable and required a catheter connection between the intra- and extraocular spaces.

Walter et al.[20] described a completely biocompatible encapsulated telemetric pressure sensor. The authors demonstrated a functional telemetric data output and energy transfer via magnetic high-frequency coupling, both in vitro and in vivo. Nevertheless, they expressed concerns about the sensor size, which was too large at that time for a capsular bag implantation. As a result, they stated the need for further miniaturization of the device. Paschalis et al.[21] recently described an autonomous IOP measurement technique using an implantable wireless transducer that provided reproducible results in conscious rabbits.[21]

Our implantation procedure described in the present study was well tolerated. By combining conventional cataract surgery with sensor implantation, we minimized the patient's stress because the procedure lasted only a few minutes longer than cataract surgery alone. The sulcus implantation and the ring shape do not cause refractive abnormalities or interference with the optical axis. However, significant astigmatism can be induced by larger corneal incisions (approximately 5.5 mm). The size of the corneal incision can be considerably decreased in future procedures by using a custom-designed insertion instrument to implant the device.

We believe that the anterior chamber inflammation reported during the early postoperative follow-up was caused by the sensor size, assuming that there was an intraocular reaction to the mechanical stress placed on the anterior eye segment. There were no indications of prolonged immunological reaction to the sensor, because the inflammation completely resolved within 9 days.

The UBM findings are interesting in terms of understanding the underlying mechanisms. We observed contact in the peripheral sulcus between the sensor and iris. This caused an anterior bulging of the affected iris segment, without angle synechiae or angle closure. These mechanical effects of the sensor on iris configuration are probably caused by the dimensions of the sensor, which was too large for pressure-free implantation in the human ciliary sulcus.

The severity of the observed inflammation and the anterior segment distress are matters of great concern. These issues must be resolved before the sensor can be applied in a larger patient population. Of major concern is the severe anterior chamber reaction with hypopyon in two patients, potentially mimicking endophthalmitis. In our view, the next development steps, in order to minimize this inflammation stimulus, are to reduce the size and adjust the shape of the intraocular sensor. These changes could resolve or at least minimize postoperative inflammation and prevent pupillary distortion by reducing the mechanical stress placed on the iris pigment epithelium during implantation. This could also reduce the pigment dispersion and prevent iris transillumination. It has been positively observed that there has been no progressive pigment dispersion or effect on IOP in terms of trabecular meshwork obstruction.

Despite these concerns about sensor size, the tolerability of the sensor was good. Although 5 of 6 patients initially showed an IOP increase at 6 months compared to the baseline, values seemed to normalize during further follow-up. The observed fluctuations, especially in patients 2 and 6, may have been associated with the underlying disease and not caused by the sensor. There was no severe IOP decompensation, endophthalmitis, prolonged inflammation, sensor dislocation, refractive instability, or retinal detachment. Furthermore, the endothelial cell count and central corneal thickness showed no significant changes during the follow-up period, which could indicate stable endothelial cell density and functionality, at least in the early postsurgical period.

There have been many reports concerning endothelial cell density after cataract surgery.[22,23] Kim and Kim[23] reported a cell loss of approximately 8% and 12% at 1 month and 6 months, respectively, after cataract surgery. In healthy eyes that have not undergone surgery, endothelial cell density declines at a rate of approximately 0.6% per year; following cataract surgery, this rate increases to 2.5% per year from 1 to 10 years after the operation.[22] This observation of declining endothelial cell density was not confirmed by our data during the postsurgical 1-year follow-up period. Apparently the patient number in this study was too small and the standard deviation of the measured values too large for a conclusive statistical
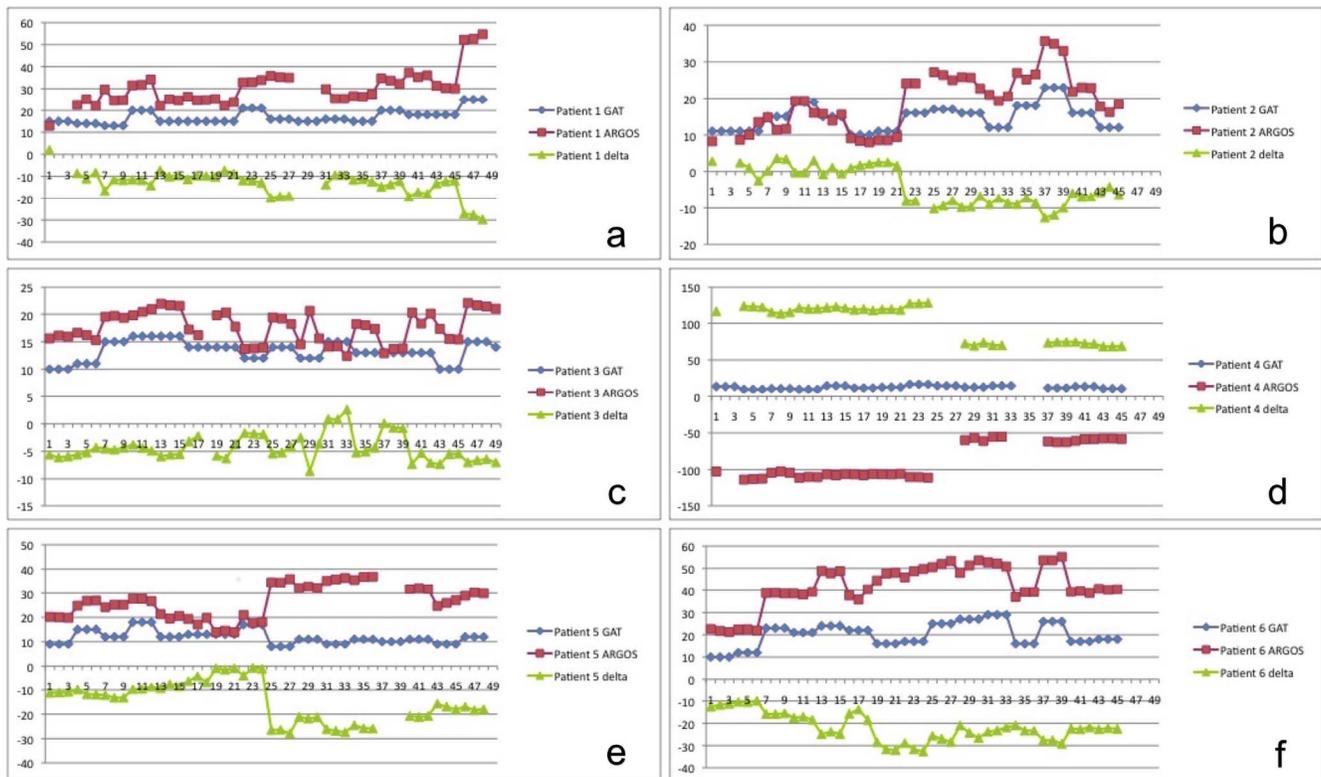
FIGURE 5. (a–f) IOP fluctuation over time (*x*-axis represents time in weeks; *y*-axis is IOP in mm Hg). *Blue line* indicates Goldmann applanation tonometry (GAT); *red line* indicates ARGOS sensor data; *green line* indicates differences (delta).

analysis. On the other hand, central corneal thickness indeed does not seem to change significantly after cataract surgery.[24]

IOP measurements could be obtained in all patients at all visits; these measurements were successfully performed by the treating physician by using the reader unit. Self-tonometry was successful in the patients' homes because the patients described no handling issues or discomfort during IOP assessment.

Comparing IOP values among patients revealed both intra- and interindividual fluctuations. Patient 4 showed a significant IOP shift immediately after implantation; this was not observed in the other patients. We assumed there was a malfunction in one of the eight capacitors of the ASIC, which could explain the negative pressure readings. The cause of this malfunction may lie in the implantation procedure. Nevertheless, this shift remained unchanged during the initial follow-up period. According to the latter, we assumed that a residual function- ality was given. Therefore, we decided to continue the assessment of IOP values, avoiding a traumatic explantation or replacement of the intraocular sensor. After approximately 7 months, a second shift occurred in patient 4, but further IOP readings remained stable until the end of the 1-year follow-up period (Fig. 5d). The exact cause and interpretation of this second change are difficult to determine. Generally, the IOP readings revealed similar pressure curve shapes compared with GAT IOP values for all patients. However, three patients had significant telemetric IOP steps after 5 to 6 months. We assume that this phenomenon, again, was the result of sensor size. A pressure effect of the ring-shaped outer diameter in the ciliary sulcus region during the healing process may account for this phenomenon.

A detailed statistical analysis does not seem reasonable because the IOP steps and the negative IOP values of patient 4 would confound the analysis. The significant variability of the

sensor readings compared to those of GAT is a major concern for their interpretation. For a clinical application, a certain calibration of the values to GAT readings would probably be necessary. However, in the future, the sensor readings could give us additional information concerning IOP control in glaucoma patients not directly related to GAT IOP values. Many questions need to be answered in further investigations. Is there a direct linear correlation between GAT and sensor readings? Are the observed fluctuations only artifacts?

Presently, it is difficult to foresee the meaning or potential of this novel technique for improving our understanding of glaucoma. To date, the results of interventional studies and treatment recommendations have been based on GAT values. The intraocular sensor could be an important diagnostic tool. It also offers the advantage of self-tonometry, which allows data collection at most times and during most activities. The device also allows patients to control and participate in their disease management.

For the first time, continuous IOP monitoring and self- tonometry using a noncontact IOP sensor seems possible in glaucoma patients. However, we must determine how to analyze and interpret these new data. Furthermore, we need to refine the sensor shape and size to avoid postoperative inflammation, pigment dispersion, and pupillary distortion. In addition, the observed telemetric IOP value steps, which were probably due to the dimensions of the sensor, which were too large, cannot be tolerated as they limit interpretation of the obtained data compared to GAT data.

References

1. Pascolini D, Mariotti SP. Global estimates of visual impairment: 2010. *Br J Ophthalmol*. 2012;96:614–618.

2. Reardon G, Kotak S, Schwartz GF. Objective assessment of compliance and persistence among patients treated for glaucoma and ocular hypertension: a systematic review. *Patient Prefer Adherence*. 2011;5:441–63.

3. Heijl A, Leske C, Bengtsson B, Hyman L, Bengtsson B, Hussein M. Reduction of intraocular pressure and glaucoma progression: results from the Early Manifest Glaucoma trial. *Arch Ophthalmol*. 2002;120:1268–1279.

4. Collaer N, Zeyen T, Caprioly J. Sequential office pressure measurements in the management of glaucoma. *J Glaucoma*. 2005;14:196–200.

5. Musch DC, Gillespie BW, Niziol LM, Lichter PR, Varma R. Intraocular pressure control and long-term visual field loss in the Collaborative Initial Glaucoma Treatment study. *Ophthalmology*. 2011;118:1766–1773.

6. Bengtsson B, Leske C, Hyman L, Heijl A. Fluctuation of intraocular pressure and glaucoma progression in the early manifest glaucoma trial. *Ophthalmology*. 2007;114:205–209.

7. Todani A, Behlau I, Fava MA, et al. Intraocular pressure measurement by radio wave telemetry. *Invest Ophthalmol Vis Sci*. 2011;52:9573–9580.

8. Melki S, Todani A, Cherfan G. An implantable intraocular pressure transducer: initial safety outcomes. *JAMA Ophthalmol*. 2014;132:1221–1225.

9. Collins CC. Miniature passive pressure transensor for implanting in the eye. *IEEE Trans Biomed Eng*. 1967;14:74–83.

10. Kakaday T, Hewitt AW, Voelcker NH, Li JS, Craig JE. Advances in telemetric continuous intraocular pressure assessment. *Br J Ophthalmol*. 2009;93:992–996.

11. Sit AJ. Continuous monitoring of intraocular pressure: rationale and progress toward a clinical device. *J Glaucoma*. 2009;18:272–279.

12. Mansouri K, Weinreb R. Continuous 24-hour intraocular pressure monitoring for glaucoma–time for a paradigm change. *Swiss Med Wkly*. 2012;142:w13545.

13. De Smedt S, Mermoud A, Schnyder C. 24-hour intraocular pressure fluctuation monitoring using an ocular telemetry sensor: tolerability and functionality in healthy subjects. *J Glaucoma*. 2012;21:539–544.

14. Mansouri K, Shaarawy T. Continuous intraocular pressure monitoring with a wireless ocular telemetry sensor: initial clinical experience in patients with open angle glaucoma. *Br J Ophthalmol*. 2011;95:627–629.

15. Leonardi M, Leuenberger P, Bertrand D, Bertsch A, Renaud P. First steps toward noninvasive intraocular pressure monitoring with a sensing contact lens. *Invest Ophthalmol Vis Sci*. 2004;45:3113–3117.

16. Doughty MJ, Zaman ML. Human corneal thickness and its impact on intraocular pressure measures: a review and meta-analysis approach. *Surv Ophthalmol*. 2000;44:367–408.

17. Svedbergh B, Backlund Y, Hok B, et al. The IOP-IOL. A probe into the eye. *Acta Ophthalmol (Copenh)*. 1992;70:266–268.

18. Schnell CR, Debon C, Pericot CL. Measurement of intraocular pressure by telemetry in conscious unrestrained rabbits. *Invest Ophthalmol Vis Sci*. 1996;37:958–965.

19. McLaren WJ, Brubaker RF, FitzSimon S. Continuous measurement of intraocular pressure in rabbits by telemetry. *Invest Ophthalmol Vis Sci*. 1996;37:966–975.

20. Walter P, Schnakenberg U, vom Bogel G, et al. Development of a completely encapsulated intraocular pressure sensor. *Ophthalmic Res*. 2000;32:278–284.

21. Paschalis EI, Cade F, Melki S, Pasquale LR, Dohlman CH, Ciolino JB. Reliable intraocular pressure measurement using automated radio-wave telemetry. *Clin Ophthalmol*. 2014;8:177–185.

22. Bourne WM. Biology of the corneal endothelium in health and disease. *Eye*. 2003;17:912–918.

23. Kim EC, Kim MS. A comparison of endothelial cell loss after phacoemulsification in penetrating keratoplasty patients and normal patients. *Cornea*. 2010;29:510–515.

24. Dooley I, Charalampidou S, Malik A, Loughman J, Molloy L, Beatty S. Changes in intraocular pressure and anterior segment morphometry after uneventful phacoemulsification cataract surgery. *Eye*. 2010;24:519–526.

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